Cold-atom circuits: exploring superfluid transport

Stephen Eckel

Joint Quantum Institute, National Institute of Standards and Technology, Gaithersburg, MD 20899

Superfluidity, or flow without resistance, is a macroscopic quantum effect that is present in a multitude of systems, including liquid helium, superconductors, and ultra-cold atomic gases. In superconductors, flow without resistance has led to the development of a number of useful devices. Here, I will present our work studying superfluid circuits, their excitations, and their analogs using circuits based on ring-shaped Bose-Einstein condensates (BECs) of sodium atoms. In superfluids, rotation acts as the analog to magnetic field in superconductors, making these devices sensitive to inertial forces rather than magnetic. To probe this sensitivity, we rotate a perturbation, or weak link, to drive transitions between between persistent current states of the superfluid. We have observed hysteresis in these transitions, measured the current-voltage and current-phase relationships of the weak link, and measured the timescales for these transitions to occur, all of which allow us to probe the microscopic mechanisms responsible for the transitions. In addition to focusing on the bulk mode (the persistent current), we have also studied the transport of phonons around the ring and used them to do minimally-destructive measurements of the persistent current states of the ring. Finally, I will discuss a more recent experiment where we drive the sudden expansion of the ring, which causes stochastic persistent currents and has analogies to the expanding universe.

FIG. 1. Experiment (top) and theory (bottom) of a supersonically-expanding ring.